THE PATHOGENIC ACTION OF QUANTUM GENERATORS (LASERS)

V. V. Shikhodyrev

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16. Abstract

Effects of intense light on the human organism is addressed in relation to the specific source, in this case optical quantum generators (OQG), better known as lasers. The bases of laser effects on the organism are presented. Reaction mechanisms and protective measures conclude the article.

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THE PATHOGENIC ACTION OF QUANTUM GENERATORS (LASERS)

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It is known that intensive sources of light have an injurious effect on /370* the organs and tissues and are a quite powerful stimulus. The irradiation of optical quantum generators (OQG), or, as they are called, lasers, causes a similar reaction in their effect on the eyes, skin and other organs, but with respect to the characteristics of this irradiation there are also certain differences.

In the last ten years a series of studies has appeared in the literature which provides concepts on the biological effect of this type of irradiation and of the pathological processes which appear in the tissues. The effects of irradiation on the eyes have been studied in most detail. Thus, the dependency of the changes which appear on various characteristics of the irradiation has been revealed and the capacity for the clinical application of irradiation for treatment and prophylaxis of certain diseases of the eye has been shown; possible mechanisms of interaction of irradiation with the tissue of the organ are examined. To a lesser extent, the materials of the investigations of interaction of irradiation with other organs and tissues, as well as with the cells of a tissue culture, preparations of certain enzymes, etc., are also presented.

The available data on these problems are provided in a number of survey articles, and monographs, as well as in the material of several conferences (B. V. Leonov, V. V. Shikhodyrov, 1966; Fine, Klein, 1965; Goldman, 1966; Ham et al., 1965; McGuff, 1966; R. Ye. Kavetskiy, V. G. Chudakov et al., 1969, and others).

The Physical Bases of Irradiation of Quantum Generators

At the base of operation of the optical quantum generator (OQF) lies the principle of induced irradiation. It appears during the electron movements of

*Numbers in the margin indicate pagination in the foreign text.

excited atoms from an upper to a lower energy level, as a result of which photons of a certain frequency are emitted. The possibility of obtaining such irradiation was examined by V. A. Fabrikant et al. (1940), while in 1954 this phenomenon was practically demonstrated in a molecular ammonia generator by N. G. Basov and A. M. Prokhorov in the USSR, and simultaneously and independently of /371 them by Townes et al. in the United States.

In 1960, Maiman created a generator in which a crystal of synthetic ruby was used in the capacity of the working material. A year later, Gavan et al. constructed a gas OQG using a mixture of helium and neon. In OQG, using solid bodies, in addition to the ruby, crystals of various halloid compounds, tungsten, titanium and molybdenum acids are used which contain admixtures of rare earth, transitional and other elements. Various systems of gas OQG have been developed in whose working substances many mixtures appear: argon-oxygen, krypton, xenon, idoine vapor, bromine, carbon monoxide, cesium vapor, etc. In 1962 the first semiconductor optical quantum generators were created; their basic advantage is the capacity for directly converting electrical energy of the current source into irradiation of the generator. The future belongs to the semiconductor OQG, since in comparison with the other types they have the highest coefficient of efficiency, exceeding 50%. Today, OQG have been made using a liquid operating element (solutions of chelates which include europium, and inorganic solutions based on trivalent neodymium) (R. Ye. Kavetskiy et al., 1969).

The region of wavelengths in which one obtains generation of the irradiation of lasers extends in range from the ultraviolet to the infrared. A high degree of monochromaticity is characteristic of this type of irradiation in the optical range. For example, for ruby lasers the hemisphere of the spectal irradiation band comprises tenths of an angstrom. The irradiation of lasers has a small angle of divergence and is theoretically limited by the phenomenon of diffraction. Thus, in modern lasers the angle of diffraction comprises only a few tenths of a minute. Finally, in differentiation from other sources of irradiation of the optical range, a high degree of spatial and temporal coherency are characteristic for laser irradiation. All these properties make it possible to focus laser irradiation into a small spot (up to a few microns) by the aid of an optical system.

Solid body lasers have extremely high energy densities in the beam. Although for the first ruby lasers the energy of irradiation comprised tenths of a joule, and the pulse power did not exceed 1 kW, in recent years, both in the USSR and abroad, models of powerful ruby and glass-neodymium lasers have been developed which have high energetic indices. In the best models of powerful lasers, the energy of irradiation attains several thousands of joules, while they attain a gigawatt of power. These capacities are determined by the size and quality of the operating element, by the care given its preparation, by the character of the feed system and by other factors (R. Ye. Kavetskiy et al., 1969).

Solid body lasers, as a rule, operate in a pulse mode, and the duration of the irradiation pulse is determined by the conditions of generation. In the free lasing mode pulse length is about 1 ms, but can be decreased to 10^{-9} seconds. Gas lasers are constant effect generators and therefore the energy characteristic of these instruments is expressed in units of power (watts).

The primary characteristics of laser irradiation, determined by the reaction of it with biological objects, are as follow: wavelength - λ, pulse length (or exposition) - t, energy of irradiation - G, angle of beam dispersion - γ.

In the region of the irradiation spectrum of lasers, the most sensitive organ is the eye, and therefore most investigations of the reaction of irradiation with tissues of the living organism have been devoted to a study of changes in the organ of vision. The creation of lasers provided a new theoretically ideal source of light for photocoagulation of the eye. Expanding the use of lasers in various fields of technology entails the necessity of a careful study of the nature of the reaction of living tissues, particularly with human tissues, to irradiation from the viewpoint of estimating and preventing danger which appears in work with such instruments. The possibility of the latter is confirmed by the reports which have appeared in the press concerning injury to the organ of human vision as the result of an accident caused both by direct and reflected laser irradiation (Jacobson et al., 1965; Zweng et al., 1967, Cutrin et al., 1968).

/372

Even in the first experiments on a study of the effect of laser irradiation on the organ of vision it was shown that the effect of ruby laser irradiation with $\lambda = 0.694\ \mu$, causes the appearance of a focus of injury on the fundus oculi, having several zones, with discoloration of the pigment in this region. The degree of pronouncement of the observed injuries is directly dependent upon the degree of pigmentation of the fundus oculi (Zaret et al., 1961, 1963; Kapany et al., 1963). Moreover, as the results of experiments of various investigators show, a dose-effect relationship is observed. At minimum, threshold energies of irradiation, one observes the appearance of small, grayish circular shaped foci of coagulation on the fundus oculi. With a slight increase in energy, large-area structured foci appear which consist of several zones with ejected pigment in the center. With a further increase in energy, rupture of the blood vessels of the vascular membrane occurs with the appearance of subretinal hemorrhages and hemorrhages in the vitreous body (Zweng et al., 1965; Geeraets et al., 1965).

During the histological investigation of the region of reaction of irradiation with eye tissues, with minimum injuries in the case of irradiation of free generation of a ruby laser with $\lambda = 0.69\ \mu$ ($t \sim 10^{-3}$ seconds), necrosis of the cells of the pigmented epithelium and of the directly adjacent segments of rods and cones of the retina. This is accompanied by slight retinal separation. Proportional to the increase in energy of irradiation, there is a widening of the zone of necrosis of the pigmented epithelium, and of the rods and cones of the retina. The layers of the vascular membrane, where capillarial rupture occurs with the formation of small hemorrhages, are drawn into the region of damage. In the underlying layers of the retina, one observes deformation of the layers, pyknosis of the nuclei of the receptor layer, and perinuclear edema. In all cases the dimensions of the region of injury in the inner layers of the retina are significantly smaller than in the outer, receptor layer and in the pigmented epithelium, which corresponds to data concerning maximum concentration of energy of irradiation in the cells of the pigmented epithelium (Marshall, Mellerio, 1967; A. F. Migacheva, 1969). With a further increase in the energy of irradiation, destruction of the larger blood vessels of the retina occurs, with more wide-spread hemorrhage, rupture

of the retina with defoliation of it about the defect and hemorrhage into the vitreous body. All the described changes characterize the central zone of destruction, i.e., the place of direct reaction of the beam with the tissues. Surrounding this, a zone of dystrophic changes develops, which is most wide-spread in the layer of rods and cones, where deterioration of the protein-polysaccharide complex of these structures occurs (A. F. Migacheva, 1969). A day after exposure, an inflammatory reaction develops in the region of injury which is accompanied by the appearance of subretinal macrophages or leucocytes. By the tenth day, formation of a chorioretinal scar occurs. During exposure to disperse irradiation of a ruby laser, in experiments performed on mice, damage to the retina also occurred which was accompanied by focal deterioration of the rods and cones (L. A. Sevast'yanova, 1965). /373

A comparison of the changes in the eye caused by exposure to laser irradiation with the picture of injury during exposure to other bright sources of light has shown that after coagulation laser injury is more clearly pronounced structurally and is less extensive in area then is the case during exposure to the Zeiss photocoagulator (Geeraets et al., 1963). On the other hand, the focus is very reminiscent of the injury caused by an ordinary light coagulator (Geeraets et al., 1965; Zweng et al., 1965).

A comparison of the effects caused by the irradiation of a ruby laser (λ = 0.69 μ) and a neodymium laser (λ = 1.06 μ) demonstrated the dependence of these on wavelengths: for obtaining minimum changes in the tissues of the fundus oculi in the case of irradiation with λ = 1.06 μ, an energy level was required that was 5-6 times greater than with λ = 0.69 μ. Such differences are explained by the dissimilar passage and absorption of irradiations of different wavelengths in the ocular media (Geeraets, et al., 1968). Notwithstanding the fact that irradiation of the neodymium laser is to a significant degree absorbed in the transparent media of the eye (about 50%), the characteristic changes, as with exposure to irradiation of the ruby laser, are necrosis of the cells of the pigmented epithelium in the region of beam abberation on the fundus oculi and in the adjacently lying structures of the outside receptor level of the retinal and vascular membranes (V. V. Shikhodyrov, A. F. Migacheva, 1969; Geeraets, 1967).

When conducting photocoagulation in experiments on animals, it was noted that the spectral range of irradiation for obtaining this effect must be between 0.4 and 0.9 μ due to the fact that transmission of the refracting media of the eye is higher in the visible than in the infrared region of the spectrum. Obtaining a small focus makes it possible to conduct coagulation in the region of the yellow spot, while short exposure time excludes the use of anesthesia (Kapany et al., 1963). Proceeding from data obtained in an experiment performed on animals, laser coagulators began to be used in medical practice. Today, this method of photocoagulation has become a quite wide-spread procedure in clinical ophthalmology (V. V. Arkhangel'skiy, 1966; N. A. Puchkovskaya et al., 1966; I. K. Kerova, 1968; M. B. Chutko, 1969; Campbell et al., 1965; Freeman et al., 1965; Berler, 1967; Baetham et al., 1970, and others).

Shortening the pulse length to 10^{-6} - 10^{-9} seconds significantly influences the character of eye tissue reaction to irradiation. It has been shown that even relatively small changes are accompanied by hemorrhage into the subretinal space (Geeraets et al., 1965; Zweng et al., 1967), at an energy which exceeds by only three times the energy causing threshold damage. At the same time, with irradiation of free generation, this relationship increases 20-30 times. Besides the similarity of character of threshold injuries caused by modulated and free pulse, effects were noted which indicate certain other mechanisms of the effect of irradiation with a shorter pulse on the tissue. Thus, for example, in the case of damage caused by modulated irradiation, in differentiation from the effect of the ordinary pulse, preservation of the /374
activity of the enzyme NAD-diaphorase in the ellipsoid receptor cells was observed (Geeraets et al., 1965; Kohtiao et al., 1966). Some authors indicate the absence of inflammatory reaction and the formation of chorioretinal scar as a characteristic of the effect of modulated irradiation (Zweng et al., 1967). The noted facts indicate the impossibility of using this irradiation in clinical practice for photocoagulation of the retina.

Of the constant action gas lasers, today the most widely used is the helium-neon with $\lambda = 0.632\ \mu$, and the argon with $\lambda = 0.514$ or $0.488\ \mu$ and the CO_2 laser with $\lambda = 10.6\ \mu$. The irradiation of the first two maximally passes through the transparent medium of the eye and, just as in the case with

the ruby laser, is concentrated in the tissues of the fundus oculi. The injuries caused by helium-neon laser irradiation are reminiscent of changes characteristic for ruby laser irradiation, but they are less clear-cut and require high energy. This can be explained by the differences in duration of action (Kohtiao et al., 1965; Blable et al., 1966; Rosan et al., 1969). The experimental investigations which have been conducted showed the possibility of using irradiation of the argon laser in clinical ophthamology for removing small aneurisms of diabetic retinopathy, since the green light is absorbed in the blood of the blood vessels to a greater extent than the irradiation of the ruby laser, and consequently, for effective treatment one can use a lower energy level. The irradiation of the CO_2 laser in the far infrared region of the spectrum is almost entirely absorbed in the cornea. Even a few watts of irradiation cause wide-spread, visibile damage to the cornea (P. I. Saprykin, 1968; Fine, 1967).

With respect to estimating the danger of laser irradiation during its action on the organ of vision, estimating the function of vision as well as the overall condition of the organism are of interest. Unfortunately, there are very few studies in this field.

Investigations of the effect of ruby laser irradiation on the biocurrents of the human retina by the aid of the method of electroretinography have shown disorders in the function of the visual analyzer which have been evaluated as the blinding effect (Tengroth et al., 1963). Nicholson et al., (1966) in experiments carried out on cats demonstrated changes indicative of a temporal disorganization of the mechanism of sight and changes in the excitability of the retina immediately after injury during exposure to irradiation of a ruby laser at an energy of 0.5 joules (t = 0.5 ms). With exposure to irradiation of ruby laser free generation in the range of energy levels employed in clinical practice (0.002-0.05 joules), certain changes in the visual analyzer as a whole were also revealed. At the moment of flash, inhibition of the electrical reaction of the cortex to the effect of the light stimulus occurs, which is manifested in suppression of the evoked potentials, an increase in frequency and decrease in amplitude of the biopotentials. The character of the changes found is unstable; after a certain amount of time one observes a

restoration in the magnitude of amplitude and frequency spectrum of the EEG, and also in the fluctuations of potentials evoked by the test stimulus (L. P. Laricheva, 1969).

Experimental investigations have established that exposure of the eyes to low intensity laser irradiation, which prevents injury to the organ of vision, causes changes in the hormonal function of the adrenal cortex in the rat. Here, changes occurred only after multiple exposures to ruby and neodymium lasers (8-10 pulses with an interval of 3-5 minutes) and after exposure to continuous irradiation of the helium-neon laser with a duration of 10-20 /375
minutes (A. I. Semenov, 1969). During exposure to the eye of the rabbit to continuous irradiation of the helium-neon laser, changes in the arterial pressure appear, particularly among animals which were kept under conditions of adaptation to darkness. Moreover, a change in the activity of cholinesterase and the concentration of potassium and sodium in the retina and peripheral blood was noted, which can entail a change in the physiological processes related to the parasympathetic region of the nervous system (A. I. Semenov, V. A. Syngayevskays, 1969).

Effect on the Skin

The skin is another critical organ with respect to laser irradiation. It is less sensitive than the eye tissue and requires quite high energy levels to obtain macroscopically visible skin injuries. One also observes a dependency of the effect on pigmentation. Thus, threshold levels for injury to hyper-pigmented skin are from 3-10 times lower than for normally pigmented skin, while injecting various dyes subcutaneously (Evans blue, Janus green, India ink) increases the absorption of irradiation (Goldman, 1965, 1966; Kuhns et al., 1965, and others).

The high sensitivity of pigmented skin to the effect of laser irradiation is used when investigation the possibility of treating tattooing (Goldman et al., 1967; Yules, Laub et al., 1967).

In the region of exposure to laser irradiation, an effect appears which is reminiscent of a thermal burn with necrosis of the epidermis and clearly limited injury of the hair follicles (Fine, Klein et al., 1963). Dependent

upon the energy of the action, burns of varying degrees of severity appear. Over the course of 2-3 weeks healing occurs, after which a macroscopically visible scar does not remain (Laor et al., 1965).

In the investigations of Helwig et al. (1965), a detailed study was made of the dynamics of the pathohistological changes in the skin of the pig following an exposure to ruby laser irradiation at low energy levels (1-40 joules). With an energy of irradiation beginning with 3 joules, there was a noticeable decrease in the activity of the enzymesuccinate- and lactate--dehydrogenase, and also of diaphorase, which was preceded by the appearance of morphological changes. Eleven days after exposure to irradiation, no changes were observed in the epidermis.

Very little is known concerning chronic exposures of the skin to laser irradiations. One can cite data on man, whose skin has been subjected to exposure to low levels of irradiation over a period of nine months. In this case, in the skin and its appendages, as well as in the blood vessels, significant changes were observed. The reactiveness of the skin increased so much that exposure at an energy level of 0.25 joules, which earlier had not caused disturbances, evoked edema, erythema and punctate hemorrhages (Goldman, 1965). According to the latter data of Goldman (1969), dryness of the skin and changes in its pigmentation developed among people who had worked for a period of seven years in contact with laser irradiation.

The Effect on Various Organs and Tissues

A study of the effect of long wave laser irradiation (0.69 and 1.06 μ) on various parts of the bodies of experimental animals has shown the capacity for deep penetration of the radiation through the tissues. During exposure to irradiation at an energy level in excess of 40 joules, in the region of the stomach, morphological changes were detected not only in the skin, but also in all tissues along the path of the ray, in the form of small foci of coagulation /376 necrosis of the muscular fibers, connective tissue, with hemorrhage and unique pyknotic and vacuolized cells (Laor et al., 1965). Fine et al. (1965), point out that in all cases of exposure of the thoracic cavity and abdominal region, a peculiarity of the picture of changes was alteration of damaged and undamaged

layers along the path of irradiation even at high energy levels (about 500 joules). Here, the relative mildness of burns of the surface tissues did not correspond to the severity of injuries to the internal organs.

Investigations of the effect of pulse laser irradiation on isolated organs of experimental animals, the liver for example, (Litwin et al., 1965; Mullins et al., 1966; B. M. Khromov et al., 1968), the spleen and kidney (Fine et al., 1965; B. M. Khromov et al., 1968), in a wide energy range (from 5 to 818 joules) have shown the appearance of crater-like limited damages in them. Here the investigation of the functional condition of the liver even with an area of damages up to 25%, did not reveal significant or long-term disorders in the organ's function (Mullins et al., 1966). In the spleen and kidney, during exposure to irradiation, similar foci of destruction appear, but they are frequently accompanied by hemorrhages. Healing of the defects terminates with the formation of a fibrous scar; on notes the formation of adhesions to the abdominal wall. Short-term exposure and the absence of hemorrhages makes it possible to use laser beams in surgery of the internal organs.

Combining the laser with the microscope has made it possible to obtain a radiation beam of less than 5 μ in diameter, with which one can cause damage to individual cells and subcellular structures. Investigations of the small blood vessels *in vivo*, carried out by the aid of the laser microscope, have shown that during exposure to irradiation at low energy levels one observe contraction of the blood vessels, while at higher energy levels— the formation of thrombi (Kochen et al., 1965; Baer et al., 1965).

The effect of focused ruby laser irradiation at an energy level of 100 joules on the region of forehead in mice causes serious neuropathological symptoms with the subsequent death of most of the test animals. Moreover, it turned out that about 10% of the incident radiation reaches the brain tissues. During the histological investigation, the development of hemorrhages in the cranial muscles, dura, cerebral cortex, cerebellum, and brain stem was found (Fine, Klein et al., 1965, and others).

Effect on Tumors

Today, there are many studies in which the antitumor effect of laser irradiation is examined. The investigations were conducted on cultures of cells and tissues, on mixed strains of tumors of laboratory animals, experimental tumors, tumors removed from people and on human tumors *in situ*. Pulse ruby lasers and glass-neodymium lasers are primarily used for this purpose. In some experiments complete or partial regression of the tumor was observed at various periods of time following the experiment (McGuff et al., 1966, and others), while in others immediate destruction of the tumor occurred (Monton et al., 1965). Certain deviations in the observed effects were the reason for differences in explaining the mechanism of the effect of the radiation on the tumors. As a possible reason for the gradual regression of the tumor, disruption of the blood supply to the tumor as the result of the effect of irradiation has been suggested (Klein et al., 1965), or inactivation of the enzymes which /377 participate in the metabolism of the tumor and destruction of the molecular bonds as the result of the formation of electrical fields (McGuff et al., 1965). However, thermal energy which appears at the moment of reaction of the irradiation with the tissue is viewed as the primary factor for tumor destruction (Minton et al., 1965; L. A. Piruzyan et al., 1967). According to McGuff's data (1966), for immediate tumor destruction it is necessary that it be subjected to exposure to irradiation with high energy density. It is obvious that after irradiation the characteristics of malignant growth can change. Thus, after prolonged exposure to irradiation from a laser a tumor did not yield growth in culture.

Possible Mechanisms of Reaction of Laser Irradiation with Biological Objects

Today, a certain concept has developed concerning the mechanisms of reaction of laser irradiation with living tissues. Tissue can primarily merely absorb the energy of irradiation, which, being converted into heat, causes a thermal burn of the tissue. The energy of lasers irradiating in the region of the spectrum ranging from the infrared to the visible portion is primarily absorbed in the granules of skin melanin and in the pigmented epithelium of the retina. As a result, rapid heating and propagation of a thermal wave occurs;

this thermal wave damages the cells which it encounters on its path. During the action of a long pulse (in milliseconds) thermal inactivation of the biological structures and molecules is most probable, with secondary reinforcement in the form of inflammatory response of the tissue (Hayes, Wolbarsth, 1968).

With a sufficiently rapid increase in temperature, evaporation of the water and cellular contents occurs, which leads to a unique explosion, the formation of water vapor, and rupture of the tissue with expansion of the gas contained in it (Goldman, 1966, and others). However, according to the opinion of other authors (Mendelson et al., 1965), the shock wave is not strong enough to evoke any changes in the biological materials.

During the action of gas lasers damages can occur at such low energy levels (25 mW) as to cause temperature deviations of only 7° (Kohtiao et al., 1966). Moreover, damages are possible at an energy power of less than 5 mW, i.e., at a less significant increase in temperature when the thermal nature of injury is excluded. Obviously, with gas lasers the effect of the shock wave does not appear, while during the action of impulse generators it does occur.

The effects of an electrical field can play a role in the mechanism of damage development. One of the results of the action of electrical fields of high intensity is the formation of free radicals, i.e., highly active substances which in their turn can cause tissue damage. The formation of free radicals in melanin containing tissues and in the skin of black mice has been observed (Derr et al., 1965), and in the pigmented regions of the skin of guinea pigs (Ye. P. Sidorik et al., 1967). Such effects as polymerization and ionization can also have significance; these effects, obviously, are only observed during the use of high energies and short pulse lengths.

At low energy densities and powers, primary significance attaches to an increase in temperature. The determination of other effects is made difficult, since for certain of these, for example, the appearance of cavitations in /378 liquids, phase transformations of liquids in solid bodies, etc., there exist threshold levels below which the given effects cannot appear due to low sensitivity of the technique employed. All the same, when explaining the

reaction of laser irradiation with living tissues, it is necessary to bear in mind possible different combinations of effects.

The Danger of Laser Irradiation and Protection Against It

Dependent upon wavelengths, various regions of the eye are damaged. Thus, at $\lambda = 0.69\ \mu$ (ruby) irradiation primarily injures the retina. Its focusing capacity increases the energy density of the irradiation striking the cornea. In critical cases the coefficient of magnification of energy density reaches 160,000. Infrared irradiation ($\lambda = 10.6\ \mu$), emitted by CO_2 lasers, is primarily absorbed in the surface tissues and primarily damages the cornea and skin of man.

Ruby lasers and glass-neodymium lasers' irradiation can be significantly retarded by pupil contraction, but in this case the danger if injuring the iris appears.

The most dangerous condition from the viewpoint of injuring the retina by pulse laser irradiation is dilation of the pupil, focused at infinity, when the diameter of image in the fundus oculi can be 0.4-1.4 μ. A retinal burn of from 1.5-3 mm and even smaller in the region between the fovea centralis in the disc of the optic nerve can lead to a significant decrease in the acuity of vision. At the same time, a small choreoretinal scar at the periphery can cause the formation of a small blind spot.

Almost nothing is known concerning the consequences of chronic exposure to threshold or subthreshold energy levels of irradiation both with respect to the eye and the skin. It is possible that at a certain frequency of repetition of pulses accumulative effects can appear.

On the basis of an analysis of much experimental data on the effect of laser irradiation on the tissues of the eye, it has become possible to summarize reports on threshold and safe levels of energy (Tables 29, 30).

Safe levels of irradiation significantly depend upon the wavelength of irradiation, pupil size, and also on the pulse length. The safe levels for ruby lasers shown in Table 33 can be viewed as professionally safe levels /379
including an arbitrary safety factor — 10 (Pavell, Galdman, 1969, and others).

For CO_2 lasers, the maximum acceptable energy level, according to the data of Fine et al., (1968) is 0.15 W/cm^2.

TABLE 29. THRESHOLD LEVELS OF RUBY LASER IRRADIATION FOR DAMAGED RETINA

Type of laser	Wavelength, μ	Energy density, joules/cm^3
Without high quality modulator	0.694	0.85
With high quality modulator	0.694	0.07
Constant action laser	White light	6 W/cm^2

TABLE 30. SAFE LEVELS OF THE EFFECT OF LASER IRRADIATION AT λ = 0.69 μ ON THE CORNEA FOR DIRECT AND REFLECTED BEAM

	Daylight illumination (pupil - 3 mm)	Laboratory (pupil - 5 mm)	Night (pupil - 7 mm)
Irradiation free generation, joules/cm^2	5×10^{-7}	2×10^{-7}	1×10^{-7}
Modulated irradiation, joules/cm^2	5×10^{-8}	2×10^{-8}	1×10^{-8}
Long-term exposure, W/cm^2	5×10^{-6}	2×10^{-6}	1×10^{-6}

During skin exposure to laser irradiation with λ = 0.69 and 1.06 μ, energy density should not exceed the recommended levels for the eye multiplied by a factor of 10^{-5}, while for CO_2 lasers with λ = 10.6 μ – the level of exposure for the eyes.

For protecting the eyes against laser irradiation there are glasses which protect against a beam of a certain wavelength. The most reliable in the region of the spectrum λ = 0.63-1.5 μ are protective glasses made of blue--green glass SZS-22 (National Standard 9411-66). The resistance of this brand of light filters to the destructive effect of ruby laser and glass-neodymium laser irradiations is determined as an energy density of several joules per cm^2. However, the protective glasses do not fully answer requirements in view of their narrow range of application and the inconvience of wearing them. To protect the skin, one can use white, soft elastic gloves made of leather or soft cardboard, and also protective creams (Goldman, 1969).

Persons who could be exposed to laser irradiation should undergo regular medical examinations including careful examination of the eyes.

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